

# U. S. NAVAL AMMUNITION DEPOT
# CRANE, INDIANA

U. S. NAVAL AMMUNITION DEPOT
Crane, Indiana 47522

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# IMPROVED ILLUMINATING FLARE

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This report was reviewed for adequacy and technical accuracy by J. D. Wise, Chemical Engineer.

Released

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## TABLE OF CONTENTS

**ABSTRACT**

1. Data are presented to show that a less expensive magnesium can be used to make an illuminating flare candle which generates at least as much light as conventional compositions. The composition utilizes an improved binder.

# IMPROVED ILLUMINATING FLARE

## A Feasibility Study

**PURPOSE**

1. The purpose of this report is to describe the completion of a feasibility study which demonstrated that a less expensive magnesium could be used to make an illuminating flare candle with equal to or better performance than the present Mk 24 Mod 4 Aircraft Parachute Flare candle by replacing the binder with an improved binder system.

## BACKGROUND

1. About one year ago, the Thiokol Chemical Corporation, under contract to the Air Force and the Navy, proceeded with the development of an advanced castable flare composition. That work is reported in reference (1). The binder used in preparing the castable formulation was a mixture of carboxyl terminated polyester resin and an epoxy resin catalyzed with iron linoleate. The test results from the cast work were most encouraging. It appeared that this binder system had certain advantages over resins which had been evaluated in the past. Specifically, when this binder system was used to cast the composition, it was observed that the luminous efficiency of the composition was at least equal to the luminous efficiency of compositions cast with other resin systems. The favorable results from this work suggested that the binder system could be used to advantage in a press candle as well as in cast candles. It is with this background that an effort was started to determine whether or not it was feasible to use the allegedly improved binder system in a pressed candle formulation.

## EXPERIMENTAL

1. Flare Description.

a. The candles prepared for tests were similar to candles in the Mk 24 Mod 4 Aircraft Parachute Flare. Additional details relating to that flare can be found in reference (2). Generally, the composition is consolidated into a paper tube with an inside diameter of 4.25 inches and with about one quarter inch wall thickness. The length of composition in the candle is about 16 inches.

2. Candle Fabrication Process.

a. Magnesium and sodium nitrate have been used extensively for making illuminating flare compositions. Their granular size is often varied to cause changes in the burning rate of the composition. Also the ratio of these ingredients causes changes in the burning rate as well as the efficiency (candle-seconds per gram). A third ingredient is added to the system. That ingredient, the binder, is normally a plastic in monomeric form which later can be polymerized to bond the composition to itself and to its container. In compositions prepared for pressing, the binder contents normally range from 3 to 5% by weight.

b. Usually, the first step is to preblend the binder and magnesium in a mixer. The mixer often used is a Simpson Mix Muller as sold by the National Engineering Company, Chicago, Illinois. The preblending process desensitizes the magnesium,

reduces the dust hazard, and inhibits surface oxidation of the magnesium particles.

c. The binder materials each are liquid in their procured form. The epoxy resin, polyester resin, and iron linoleate are preblended prior to addition to the magnesium.

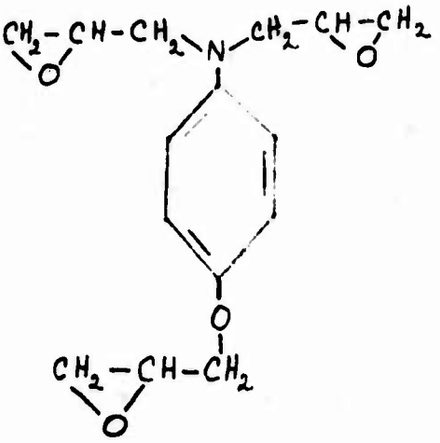
d. The sodium nitrate is later added to the preblend. This mass is then mixed until a homogeneous blend is obtained. When the binder content is about 4 to 4.5 percent, the composition has the appearance of being slightly damp. The next step in making a flare consists of taking weighed increments of the composition, placing them in the candle case, and then consolidating that composition under high pressure. A sixty ton press is normally used to consolidate the composition in a Mk 24 tube. This results in a consolidation pressure of near 8400 psi. Since the binder utilized in these experiments requires an elevated temperature cure, the candles are next placed in a curing room whose temperature is maintained at approximately 150°F. The candle composition is effectively cured at this temperature in about 48 to 60 hours.

3. Materials.

a. The source of the ingredients used in making the illuminating composition is given in Appendix I. Because this study deals primarily with the binders used, the following additional information is included.

b. The formula for the epoxy-polyester system, consists of about 77.5% Formrez F17-80 polyester resin, 19.5%, ERLD-0500 epoxy resin, and 3.0% iron linoleate.

c. The epoxy resins ERLD-0500 and ERL-0510 are both products of Union Carbide Corporation manufactured under U. S. Patent 2,951,825. The idealized structure is:



The two products are triglycidyl derivatives of para-amino phenol. ERLD-0500 is the reaction product of para-amino phenol and epichlorohydrin in the presence of caustic. Like all such products, ERLD-0500 contains some polymeric material with pendant hydroxyl groups. Commercially produced, ERLD-0500 has a viscosity of 2000 to 5000 cps at room temperature. The presence of hydroxyl groups in the material produces some catalytic effects and hence shortens potlife. To overcome this, the ERLD-0500 is molecularily distilled to produce a product known as ERL-0510 which is essentially the monomeric triglicidyl derivative of para-amino

phenol. It is a pale straw-colored liquid with a viscosity of 400 to 700 cps*.

d. Formrez F17-80 is a carboxyl terminated polyester produced by Witco Chemical Company. Its emperical formulation and typical analysis is:

Emperical Formulation

$C_{1.6} H_{2.55} O_{1.0}$

Typical Analysis

| | |
|---|---|
| Hydroxyl No. | 3.0 |
| Acid No. | 72.0 |
| Moisture, % | 0.04 |
| Viscosity, cps @ 25°C | 40,000 |

e. Source data and information about the remaining ingredients such as magnesium, sodium nitrate, and iron linoleate may be found in Appendix I.

4. Test Procedure.

a. All of the candles were burned in an inverted position, that is, with the flame pointed downward. The units were either tested in the photometric tunnel or at the MAPI site. Units tested in the photometric tunnel are given a test number prefixed with the letter T. The test number for units tested at MAPI are prefixed with the letter M. For those persons who are not familiar with the MAPI site, additional details may be found on page 11 of reference (3). The units tested in the photometric tunnel were tested using the procedure described in reference (4) for Mk 24 Aircraft Parachute Flares.

*From Union Carbide Product Data sheets.

## DISCUSSION

1. Candle Performance.

a. The luminous efficiency of an illuminating candle is a measure of its performance. That value is normally presented in units of candle-seconds per gram. Table I, which is a tabulation of the properties of the flare tested, shows clearly that units containing binder formula #2 are more efficient than units containing binder formula #1 or #3. Generally, standard Mk 24 Flares when tested in the tunnel exhibit a luminous efficiency of 48 to 50,000 candle-seconds per gram. This was the value expected for the units in Table I identified with binder formula #3. However, because the units burned too rapidly, a minor decrease in the efficiency is observed. Another binder system, identified as binder formula #1 in Table I, is an epoxy formula which gives efficiencies comparable to the Mk 24 Flare. The most remarkable result of this work is the luminous efficiency data for the epoxy-polyester resin system identified as binder formula #2. That series of units shows efficiencies considerably greater than 50,000 candle-seconds per gram. It is noteworthy that these levels of performance were achieved with a low cost magnesium. (Note added in proof: See Table IX in Appendix II for more conclusive data.)

2. Economics.

a. It has already been mentioned that the magnesium used to achieve these high levels of luminous efficiency is a material which costs much less than the material now being used in the

**TABLE I**

4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES — 29 May 1968

| TUNNEL (T) TEST | 7044 | 7045 | 7714 | 7046 | 7047 | 7048 | 7043 | 7049 | 7050 | 7710 | 7711 | 7712 | 7713 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnesium, gran 18, % | 58 | 57 | 58 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Magnesium, RMC-20, % | -- | -- | -- | 58 | -- | -- | 53 | -- | -- | 58 | -- | -- | -- |
| Magnesium, RMC-60, % | -- | -- | -- | -- | -- | -- | 5 | -- | -- | -- | -- | -- | -- |
| Magnesium, RMC-+30, % | -- | -- | -- | -- | 58 | 57 | -- | 58 | 57 | -- | 59 | 59 | 59 |
| Sodium Nitrate, 30μ, % | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 36.5 | 35.5 | 36.5 |
| Iron Filings, % | -- | 1 | -- | -- | -- | 1 | -- | -- | 1 | -- | -- | 1 | -- |
| Binder Formula, * % | 4.5 (3) | 4.5 (3) | 4.5 (3) | 4.5 (1) | 4.5 (1) | 4.5 (1) | 4.5 (2) | 4.5 (2) | 4.5 (2) | 4.5 (2) | 4.5 (2) | 4.5 (2) | 4.5 (2) |
| Luminous Intensity ($x10^6$cd) | 2.24 | 2.35 | 2.35 | 1.94 | 1.82 | 2.07 | 2.18 | 2.03 | 1.76 | 1.81 | 1.92 | 1.93 | 1.91 |
| Burning Time (sec) | 144 | 136 | 129 | 172 | 177 | 153 | 168 | 197 | 211 | 193 | 186 | 165 | 176 |
| Efficiency ($x10^3$ cd-sec/g) | 47.4 | 47.0 | 44.5 | 48.8 | 47.0 | 46.4 | 53.7 | 58.7 | 54.4 | 51.4 | 52.5 | 47.0 | 49.5 |
| Burning Rate (in/sec) | .111 | .117 | .126 | .094 | .091 | .105 | .096 | .083 | .074 | .082 | .086 | .097 | .090 |
| Burning Rate (sec/in) | 9.0 | 8.5 | 7.9 | 10.5 | 10.9 | 9.4 | 10.3 | 12.0 | 13.4 | 12.0 | 11.6 | 10.3 | 11.0 |
| Burning Rate (g/sec) | 47.2 | 50.0 | 52.6 | 39.6 | 38.5 | 44.5 | 40.5 | 34.5 | 32.2 | 35.2 | 36.5 | 41.2 | 38.6 |
| Density ($g/cm^3$) | 1.83 | 1.83 | 1.79 | 1.80 | 1.80 | 1.81 | 1.80 | 1.78 | 1.85 | 1.82 | 1.82 | 1.82 | 1.84 |
| Composition Weight ($x10^3$g) | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 |
| Consolidation Pressure (psi) | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 |
| Age of Candle (Days) | 6 | 6 | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 8 | 7 | 7 | 7 |

* (1) Epoxy formula: 68% DER 321 and 32% DEH 31.
(2) Epoxy-Polyester formula: 77.5% Formrez F-17-80, 19.5% ERLD-0500, and 3.0% Iron Linoleate.
(3) Polyester formula: 98.5% Laminac 4116 and 1.5% Lupersol DDM.

standard Mk 24 Flare. For ethical reasons, exact material prices for magnesium and binders which were used to make the study of economics will not be provided. It can be stated, however, that the polyester resin Formrez F17-80 and the epoxy resins ERLD-0500 are both substantially more costly than the Laminac resin presently used in the Mk 24 Flare. Likewise, the 30/50 atomized magnesium used in the Mk 24 Flare is also considerably more expensive than is magnesium identified by grades RMC-20, RMC-60, or RMC-+30. When the analysis is made, it is found that the low magnesium cost far offsets the higher priced binder. The net result is that if magnesium is used wherein the magnesium content is 53% RMC-20 and 5% RMC-60, and after allowing for the increased binder cost, the savings are estimated between $.80 and $1.00 per candle. The savings would be substantially larger if RMC-+30 were utilized as the magnesium in the new formula. Appendix II contains tables which show the performance of candles using other magnesiums.

3. Elevated Temperature Cure

a. The epoxy-polyester formula consisting of Formrez F17-80 and epoxy ERLD-0500 as utilized in this feasibility study requires an elevated temperature cure. It was mentioned previously that about 48 to 60 hours at 150°F for a candle of this size (15 lbs.) is adequate. For some producers, especially those who are not presently equipped with large heated storage rooms, such an elevated temperature cure requirement would present no problem. If the cure schedule as described is

unacceptable, it is suggested that this binder could be converted to a room temperature cure. Such action would, of course, introduce a tendency toward a higher exotherm during polymerization as well as shorter potlife. Thus, corresponding processing adjustments would have to be made.

b. Tables III and IV of Appendix II show a series of candles which were tested when the candles were at varying age. These series were made and tested because it had been suspected that the candles were not curing properly. As can be seen by the study, the luminous efficiency of both of these series increases as the age of the candle increases. This characteristic is not one which is normally expected. It may result, however, from the fact that the epoxy resins utilized were approximately nine months old and had pre-polymerized considerably during their storage period. Such a condition does not normally occur when a fresh supply of resin (less than three months old) is used.

## CONCLUSIONS

1. It has been demonstrated that a Mk 24 size candle can be pressed using illuminating composition which contains a low-cost magnesium without sacrifice to the luminous efficiency of the unit. As a matter of fact, it has been showed that it is possible to increase the luminous efficiency while using the low-cost magnesium when the present polyester resin is replaced with the epoxy-polyester binder formula described in this report. It was estimated further that by change to the improved binder formula and to the low-cost magnesium, the illuminating candle cost can be reduced in the neighborhood of $1.00 per unit. With this report, the feasibility study is considered to be complete. Further development and evaluation is recommended as the next immediate step.

ACKNOWLEDGEMENTS

1. The study was supported by LT. Margaret A. Frederick, Naval Air Systems Command, Code AIR-350F, Washington, D. C. The composition was mixed and pressed under the direction of Mr. Gary Norris, R&D Department, NAD Crane.

REFERENCES

1. McDermott, J. M., Advanced Castable Flare Illuminant, RDTR 99, U. S. Naval Ammunition Depot, Crane, Indiana, August 1967.

2. Pyrotechnic, Screening, and Dye-Marking Devices, NAVWEPS OP 2213, Naval Ordnance Systems Command, Washington, D. C. 20360, first revision, 1 October 1965, with 16 changes through 1 February 1968.

3. Douda, B. E., 25 Million Candle Cast Flare, Diameter, and Binder Study, RDTR No. 105, Volumes I and II, U. S. Naval Ammunition Depot, Crane, Indiana, January 1968.

4. Flare, Aircraft Parachute Mk 24 Mods, NAVORD OS 8786H with Amendment 1 of 4 January 1968.

## APPENDIX I

### List of Materials

| | |
|---|---|
| Formrez F17-80<br>Carboxyl terminated<br>polyester resin | Witco Chemical Co.<br>75 E. Walker Drive<br>Chicago, Illinois 60601<br>Phone: 312-346-2960<br>Attn: Mr. Hannason |
| Epoxy Resin ERL-0510<br>Thiokol Chemical Corp.<br>Specification TWS-RM-1003 | Union Carbide Corp.<br>230 North Michigan Ave.<br>Chicago, Illinois 60601<br>Phone: Area 312-346-3300 |
| Epoxy Resin ERLD-0500<br>Thiokol Chemical Corp.<br>Specification TWS-RM-64 | Union Carbide Corp.<br>Plastics Division<br>2330 Victory Parkway<br>Cincinnatti, Ohio 45206<br>Phone: 513-272-0202<br>Attn: Miss Oldiges |
| Iron Linoleate<br>Thiokol Chemical Corp.<br>Specification TWS-RM-1002 | Harshaw Chemical Co.<br>1945 East 97th St.<br>Cleveland, Ohio 44106<br>Phone: 216-721-8300<br>Attn: Mr. Bill Riese |
| Sodium Nitrate | Davies Nitrate Co.<br>P. O. Box 306<br>Metuchen, N. J. 08840<br>Attn: Mr. A. Wheaton |
| Magnesium<br>Other than RMC grades | Valley Metallurgical Processing Co.<br>Essex, Conn. 06426 |
| Magnesium, all grades<br>whose number is prefixed<br>with the initials RMC | Reade Manufacturing Corp.<br>Lakehurst, N. J. |
| Dow Epoxy Resin DER 321<br>Dow Epoxy Hardner DEH 31 | Dow Chemical Co.<br>3909 North Meridian St.<br>Indianapolis, Indiana 46208<br>Phone: 317-926-3441<br>Attn: Mr. Joe O'Brien |

## APPENDIX II

Contains Tables II through IX

**TABLE II**

4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES 10 May 1968

| TUNNEL(T) TEST | T6305 | T6306 | T6310 | T6307 | T6308 | T6311 | T6309 | T6314 | T6312 | T6313 |
|---|---|---|---|---|---|---|---|---|---|---|
| Magnesium, gran 18, % | -- | -- | -- | -- | -- | -- | -- | -- | 58 | 57 |
| Magnesium, RMC-20, % | 53 | 53 | 52 | 53 | 53 | -- | 53 | 53 | -- | -- |
| Magnesium, RMC-60, % | 5 | 5 | 5 | 5 | 5 | -- | 5 | 5 | -- | -- |
| Magnesium, RMC-+30, % | -- | -- | -- | -- | -- | 58 | -- | -- | -- | -- |
| Sodium Nitrate, 30μ, % | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| Iron Filings, % | -- | -- | 1 | -- | -- | -- | -- | -- | -- | 1 |
| Binder Formula, * % | 4.5 (1) | 4.5 (2) | 4.5 (1) | 4.5 (3) | 4.5 (4) | 4.5 (3) | 4.5 (5) | 4.5 (6) | 4.5 (7) | 4.5 (7) |
| Luminous Intensity ($x10^6$cd) | 1.88 | 1.76 | 2.38 | 1.86 | 1.73 | 1.60 | 1.70 | 1.45 | 1.70 | 1.70 |
| Burning Time (sec) | 165 | 157 | 99 | 179 | 196 | 200 | 161 | 160 | 186 | 156 |
| Efficiency ($x10^3$ cd-sec/g) | 45.6 | 40.6 | 34.6 | 49.0 | 50.0 | 47.0 | 40.4 | 34.0 | 46.6 | 39.0 |
| Burning Rate (in/sec) | 0.097 | 0.102 | 0.165 | 0.091 | 0.082 | 0.082 | 0.100 | 0.100 | 0.086 | 0.103 |
| Burning Rate (sec/in) | 10.2 | 9.7 | 6.1 | 10.8 | 12.1 | 12.1 | 9.9 | 10.0 | 11.5 | 9.6 |
| Burning Rate (g/sec) | 41.2 | 43.3 | 68.8 | 37.9 | 34.6 | 35.8 | 42.3 | 42.5 | 36.5 | 43.6 |
| Density ($g/cm^3$) | 1.81 | 1.81 | 1.80 | 1.78 | 1.80 | 1.76 | 1.81 | 1.82 | 1.81 | 1.81 |
| Composition Weight ($x10^3$g) | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 |
| Consolidation Pressure(psi) | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 |
| Age of Candle (Days) | 9 | 9 | 8 | 8 | 8 | 8 | 8 | 7 | 7 | 7 |

*(1) Epoxy formula: 68% DER 321 and 32% DEH 31.
(2) Epoxy formula: 66% DER 321, 32% DEH 31, and 2% Iron Linoleate.
(3) Epoxy-Polyester formula: 78.7% Formrez F-17-80, 20% ERLD-0500, and 1.3% Iron Linoleate.
(4) Epoxy-Polyester formula: 77.5% Formrez F-17-80, 19.5% ERLD-0500, and 3.0% Iron Linoleate.
(5) Epoxy-Polyglycol formula: 38% DER 732 and 62% QX 3812.
(6) Epoxy-Polyglycol formula: 37.5% DER 732, 60.5% QX 3812, and 2.0% Iron Linoleate.
(7) Polyester formula: 98.5% Laminac 4116 and 1.5% Lupersol DDM.

## TABLE III

### 4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES

| MAPI (M)/TUNNEL(T) TEST | T3869 | T4190 | T4721 | T5066 | T5503 | T5687 | T6303 ** | M683 ** | T6299 ** | M669 ** |
|---|---|---|---|---|---|---|---|---|---|---|
| Magnesium, RMC-20, % | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | P | P |
| Magnesium, RMC-60, % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | P | P |
| Sodium Nitrate, 30 μ, % | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | P | P |
| Epoxy-Polyester Binder, *% | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | P | P |
| Luminous Intensity ($x10^6$cd) | 1.85 | 1.91 | 1.87 | 1.99 | 1.89 | 2.07 | 1.53 | 1.77 | 1.47 | 1.70 |
| Burning Time (sec) | 173 | 171 | 188 | 162 | 193 | 173 | 198 | 176 | 197 | 176 |
| Efficiency ($x10^3$ cd-sec/g) | 47.5 | 48.0 | 51.8 | 47.4 | 53.7 | 52.7 | 44.6 | 46.0 | 42.5 | 44.2 |
| Burning Rate (in/sec) | 0.093 | 0.094 | 0.086 | 0.100 | 0.088 | 0.093 | 0.081 | 0.092 | 0.086 | 0.093 |
| Burning Rate (sec/in) | 10.7 | 10.5 | 11.5 | 9.9 | 11.7 | 10.6 | 12.2 | 10.7 | 11.9 | 10.6 |
| Burning Rate (g/sec) | 39.0 | 39.7 | 36.0 | 41.9 | 35.1 | 39.3 | 34.3 | 38.6 | 34.5 | 38.4 |
| Density ($g/cm^3$) | 1.80 | 1.81 | 1.80 | 1.80 | 1.79 | 1.81 | 1.81 | 1.80 | 1.77 | 1.76 |
| Composition Weight ($x10^3$g) | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.7 |
| Consolidation Pressure (psi) | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 |
| Age of Candle (Days) | 6 | 13 | 20 | 27 | 35 | 41 | 56 | 56 | -- | -- |

* Epoxy-Polyester formula: 81.89% Formrez F-17-80, 17.0% ERLD-0500, and 1.11% Iron Linoleate.

**These units were integrated over the total burning time to obtain the average luminous intensity. For the remaining T units, the integral between 10 sec. and 160 sec. divided by 150 represents the reported intensity. Also, Standard Lamp 9789 was used in calibration. Data taken against Lamp 9789 in the test tunnel (T) is about 10% lower than data against Lamp 6030 which was used on the remaining units.

P=MK24 Mod 4 Production candle.

3 May 68

## TABLE IV

### 4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES

| MAPI (M)/TUNNEL(T) TEST | T3868 | T4189 | T4720 | T5065 | T5502 | T5686 | T6302 ** | M682 ** | T6301 ** | M679 ** |
|---|---|---|---|---|---|---|---|---|---|---|
| Magnesium, RMC-E305, % | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 | P | P |
| Sodium Nitrate, 30μ, % | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | P | P |
| Epoxy-Polyester Binder, *% | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | P | P |
| Luminous Intensity ($x10^6$cd) | 1.89 | 1.54 | 1.52 | 1.94 | 1.83 | 1.55 | 1.55 | 1.30 | 1.42 | 1.65 |
| Burning Time (sec) | 191 | 219 | 233 | 168 | 213 | 221 | 200 | 210 | 195 | 174 |
| Efficiency ($x10^3$ cd-sec/g) | 53.3 | 49.6 | 52.1 | 47.9 | 57.3 | 50.4 | 46.5 | 40.1 | 40.8 | 42.4 |
| Burning Rate (in/sec) | 0.084 | 0.073 | 0.069 | 0.096 | 0.075 | 0.072 | 0.081 | 0.076 | 0.084 | 0.094 |
| Burning Rate (sec/in) | 11.8 | 13.5 | 14.3 | 10.3 | 13.2 | 13.6 | 12.3 | 13.0 | 11.8 | 10.5 |
| Burning Rate (g/sec) | 35.5 | 31 | 29.0 | 40.4 | 31.9 | 30.7 | 34.0 | 32.3 | 34.9 | 38.8 |
| Density (g/cm$^3$) | 1.81 | 1.81 | 1.79 | 1.81 | 1.81 | 1.82 | 1.79 | 1.82 | 1.77 | 1.76 |
| Composition Weight ($x10^3$g) | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.7 |
| Consolidation Pressure (psi) | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 |
| Age of Candle (Days) | 14 | 22 | 29 | 36 | 44 | 50 | 56 | 56 | -- | -- |

* Epoxy-Polyester formula: 81.89% Formrez F-17-80, 17.0% ERL 0510, and 1.11% Iron Linoleate.

**These units were integrated over the total burning time to obtain the average luminous intensity. For the remaining T units, the integral between 10 sec. and 160 sec. divided by 150 represents the reported intensity. Also, Standard Lamp 9789 was used in calibration. Data taken against Lamp 9789 in the test tunnel (T) is about 10% lower than data against Lamp 6030 which was used on the remaining units.

P=MK24 Mod 4 Production candle.

3 May 1968

**TABLE V**

**4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES**

| MAPI (M)/TUNNEL(T) TEST | T3870 | T4191 | T4722 | T5067 | T5504 | T5688 | T6304** | M681** | T6300** | M670** |
|---|---|---|---|---|---|---|---|---|---|---|
| Magnesium, RMC-20, % | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | P | P |
| Magnesium, RMC-60, % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | P | P |
| Sodium Nitrate, 30 μ, % | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | P | P |
| Epoxy-Polyester Binder, *% | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | P | P |
| Luminous Intensity ($x10^6$cd) | 1.84 | 1.89 | 1.87 | 1.86 | 1.91 | 1.98 | 1.65 | 1.64 | 1.45 | 1.68 |
| Burning Time (sec) | 156 | 172 | 181 | 180 | 186 | 180 | 186 | 175 | 197 | 176 |
| Efficiency ($x10^3$ cd-sec/g) | 42.3 | 47.8 | 49.8 | 49.3 | 52.3 | 52.5 | 45.1 | 42.2 | 42.0 | 42.2 |
| Burning Rate (in/sec) | 0.104 | 0.094 | 0.088 | 0.089 | 0.086 | 0.089 | 0.086 | 0.091 | 0.086 | 0.093 |
| Burning Rate (sec/in) | 9.6 | 10.5 | 11.3 | 11.2 | 11.5 | 11.2 | 11.6 | 10.9 | 11.9 | 10.6 |
| Burning Rate (g/sec) | 43.6 | 39.5 | 37.5 | 37.7 | 36.5 | 37.7 | 36.5 | 38.8 | 34.5 | 38.4 |
| Density ($g/cm^3$) | 1.80 | 1.80 | 1.83 | 1.82 | 1.82 | 1.82 | 1.83 | 1.83 | 1.77 | 1.76 |
| Composition Weight ($x10^3$g) | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.7 |
| Consolidation Pressure (psi) | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 |
| Age of Candle (Days) | 6 | 13 | 20 | 27 | 35 | 41 | 56 | 56 | -- | -- |

* Epoxy-Polyester formula: 81.89% Formrez F-17-80, 17.0% ERL 0510, and 1.11 % Iron Linoleate.

**These units were integrated over the total burning time to obtain the average luminous intensity. For the remaining T units, the integral between 10 sec. and 160 sec. divided by 150 represents the reported intensity. Also, Standard Lamp 9789 was used in calibration. Data taken against Lamp 9789 in the test tunnel (T) is about 10% lower than data against Lamp 6030 which was used on the remaining units.

P=MK24 Mod 4 Production candle.

**TABLE VI**

**4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES**

| MAPI (M)/TUNNEL(T) TEST | T16854 | M705 | M713 | M714 | T1187 | T1530 | T1933 | T2550 |
|---|---|---|---|---|---|---|---|---|
| Magnesium % | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 |
| (granulation) | RMC20 | RMC20 | RMC20 | RMC20 | RMC20 | RMC20 | RMC20 | RMC20 |
| Sodium Nitrate % | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| (particle size) | 30μ | 30μ | 30μ | 30μ | 30μ | 30μ | 30μ | 30μ |
| Binder* % | | | | | | | | |
| Epoxy-Polyester | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Luminous Intensity ($x10^6$cd) | 1.87 | 1.49 | 1.28 | 1.24 | 1.98 | 1.97 | 1.68 | 1.52 |
| Burning Time (sec) | 199 | 169 | 206 | 202 | 169 | 195 | 213 | 213 |
| Efficiency ($x10^3$ cd-sec/g) | 54.6 | 37.5 | 38.8 | 37.4 | 49.3 | 56.5 | 52.8 | 47.3 |
| Burning Rate(in/sec) | 0.08 | 0.09 | 0.07 | 0.08 | 0.09 | 0.08 | 0.07 | 0.07 |
| Burning Rate (sec/in) | 12.3 | 10.9 | 12.7 | 11.9 | 10.5 | 12.0 | 13.2 | 13.2 |
| Burning Rate (g/sec) | 34 | 40.3 | 32.9 | 33.7 | 40.2 | 34 | 31 | 31 |
| Density ($g/cm^3$) | 1.81 | 1.80 | 1.81 | 1.80 | 1.82 | 1.80 | 1.82 | 1.81 |
| Composition Weight ($x10^3$g) | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 |
| Consolidation Pressure (psi) | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 |

* Epoxy-Polyester formula: 81.89% Formrez F-17-80, 17.0% ERL 0510, and 1.11% Iron Linoleate.

**TABLE VII**

4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES

23 January 1968

| MAPI (M)/TUNNEL(T) TEST | M696 | M672 | M693 | T16701 | T16854 | M704 | M705 |
|---|---|---|---|---|---|---|---|
| Magnesium % | 58 | 58 | 58 | 58 | 58 | 58 | 58 |
| (granulation) | 17 | 17 | 17 | 17 | RMC 20 | ** | RMC 20 |
| Sodium Nitrate % | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| (particle size) | 30μ | 30μ | 30μ | 30μ | 30μ | 30μ | 30μ |
| Binder* % | | | | | | | |
| Epoxy-Polyester | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Luminous Intensity ($x10^6$cd) | | 2.2 | | 1.97 | 1.87 | 1.52 | 1.49 |
| Burning Time (sec) | 130 | 126 | 132 | 123 | 139 | 136 | 169 |
| Efficiency ($x10^3$ cd-sec/g) | | 42.3 | | 35.8 | 54.6 | 30.4 | 37.5 |
| Burning Rate (in/sec) | .12 | .13 | .12 | .13 | .08 | 0.11 | 0.09 |
| Burning Rate (sec/in) | 7.9 | 7.7 | 7.8 | 7.5 | 12.3 | 8.3 | 10.9 |
| Burning Rate (g/sec) | 52 | 53 | 50 | 55 | 34 | 50 | 40.3 |
| Density ($g/cm^3$) | 1.77 | 1.75 | 1.71 | 1.77 | 1.81 | 1.80 | 1.80 |
| Composition Weight ($x10^3$g) | 6.7 | 6.7 | 6.7 | 6.7 | 6.8 | 6.8 | 6.8 |
| Consolidation Pressure (psi) | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 |

* Epoxy-Polyester formula: 3.68% Formrez F-17-80, .77% ERL 0510, and .05% Iron Linoleate.
P-denotes MK 24 MOD 4 AP Flare Candle.

**** 60% granulation 18 magnesium and 40% RMC 60 magnesium.**

## TABLE VIII

4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES — 3 January 1968

| MAPI (M)/TUNNEL(T) TEST | T13748 | T13750 | T13749 | T13751 | M670 | M692 | M695 | T16699 | T16700 | M671 | M694 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnesium % | 58 | | 58 | | 58 | 58 | 58 | 58 | 58 | 58 | 58 |
| (granulation) | 18 | | 18 | | RMC 60 | RMC 60 | RMC 60 | ** | RMC 60 | 12 | 12 |
| Sodium Nitrate % | 37.5 | | 37.5 | | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| (particle size) | 30 μ | | 30 μ | | 30 μ | 30 μ | 30 μ | 30 μ | 30 μ | 30 μ | 30 μ |
| Binder* % | | P | | P | | | | | | | |
| Epoxy-Polyester | 4.5 | | 4.5 | | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Luminous Intensity ($x10^6$cd) | 1.58 | 1.89 | 1.55 | 1.95 | 2.4 | | | 1.94 | 2.37 | 2.9 | |
| Burning Time (sec) | 223 | 189 | 241 | 187 | 129 | 123 | 129 | 133 | 90 | 68 | 69 |
| Efficiency ($x10^3$ cd-sec/g) | 50.3 | 47.4 | 53.4 | 48.1 | 47.5 | | | 38.0 | 32.2 | 29.9 | |
| Burning Rate (in/sec) | .07 | .09 | .06 | .09 | .12 | .13 | .12 | .12 | .18 | .24 | .24 |
| Burning Rate (sec/in) | 14.3 | 10.2 | 14.3 | 10.1 | 7.8 | 7.2 | 7.7 | 8.0 | 5.4 | 4.1 | 4.1 |
| Burning Rate (g/sec) | 31 | 37 | 29 | 40 | 51 | 53 | 51 | 51 | 73 | 99 | 96 |
| Density ($g/cm^3$) | 1.90 | 1.76 | 1.87 | 1.76 | 1.70 | 1.66 | 1.70 | 1.78 | 1.70 | 1.75 | 1.72 |
| Composition Weight ($10^3$g) | 7.0 | 6.7 | 7.0 | 6.7 | 6.6 | 6.6 | 6.6 | 6.8 | 6.6 | 6.7 | 6.6 |
| Consolidation Pressure (psi) | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 | 8450 |

* Epoxy-Polyester formula: 3.68% Formrez F-17-80, .77% ERL 0510, and .05% Iron Linoleate.
**60% granulation 18 magnesium and 40% RMC 60 magnesium.
P-denotes MK 24 MOD 4 AP Flare Candle.

TABLE IX

4.25" DIAMETER SOLID PRESSED FLARES IN PAPER TUBES — 11 July 1968

| TUNNEL(T) TEST | T10158 | T10159 | T10160 | T10161 | T10162 |
|---|---|---|---|---|---|
| Magnesium, %* | 58 | 58 | 58 | 58 | 58 |
| Sodium Nitrate, 30μ, % | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 |
| Binder, %** | 4.5(1) | 4.5(1) | 4.5(1) | 4.5(1) | 4.5(2) |
| Luminous Intensity ($x10^6$cd) | 1.90 | 1.71 | 1.79 | 1.69 | 1.96 |
| Burning Time (sec) | 195 | 214 | 202 | 213 | 172 |
| Efficiency ($x10^3$ cd-sec/g) | 54.5 | 53.8 | 54.2 | 53.4 | 49.9 |
| Burning Rate (in/sec) | 0.081 | 0.075 | 0.079 | 0.075 | 0.094 |
| Burning Rate (sec/in) | 12.2 | 13.2 | 12.6 | 13.2 | 10.6 |
| Burning Rate (g/sec) | 34.8 | 31.7 | 33.5 | 31.7 | 39.2 |
| Density ($g/cm^3$) | 1.83 | 1.81 | 1.82 | 1.81 | 1.80 |
| Composition Weight ($x10^3$g) | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 |
| Consolidation Pressure (psi) | 8450 | 8450 | 8450 | 8450 | 8450 |
| Age of Candle (Days) | 8 | 8 | 8 | 8 | 8 |

* T10162 contains Granulation 18 atomized magnesium.
The remaining units contain RMC-430 ellipsoidal magnesium.

** (1) Epoxy - polyester formula: 77.5% Formrez F17-80, 19.5% ERLD-0500, and 3.0% Iron Linoleate.

(2) Polyester formula: 98.5% Laminac 4116 and 1.5% Lupersol DDM.

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13. ABSTRACT

Data are presented to show that a less expensive magnesium can be used to make an illuminating flare candle which generates at least as much light as conventional compositions. The composition utilizes an improved binder.

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